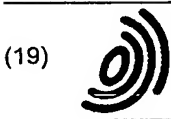


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(11) EP 1 510 871 A2

## (12) EUROPEAN PATENT APPLICATION

(43) Date of publication:  
02.03.2005 Bulletin 2005/09

(51) Int Cl.7: G03F 7/20

(21) Application number: 04254940.2

(22) Date of filing: 17.08.2004

(84) Designated Contracting States:  
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IT LI LU MC NL PL PT RO SE SI SK TR  
Designated Extension States:  
AL HR LT LV MK

(30) Priority: 29.08.2003 EP 03255377

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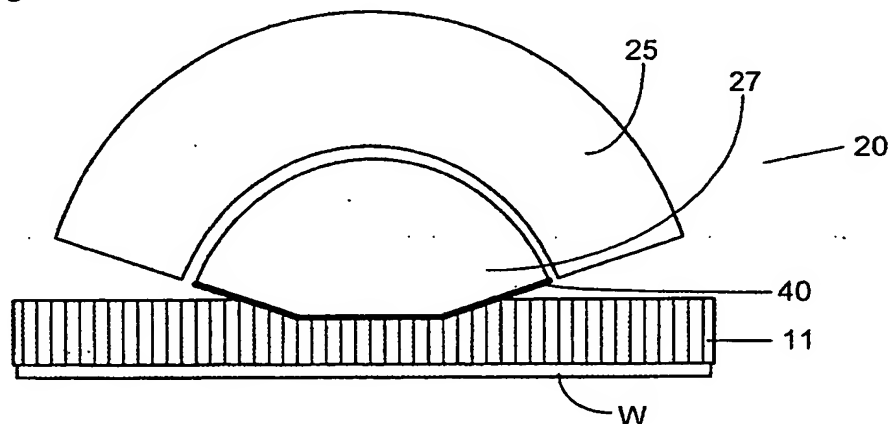
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## (54) Lithographic apparatus and device manufacturing method

(57) A lithographic projection apparatus is disclosed for use with an immersion liquid positioned between the final element of the projection system and the substrate W. Several methods are disclosed for protecting components of the projection system, substrate table and a

liquid confinement system. These include providing a protective coating (40) on the final element (20) of the projection system as well as providing sacrificial bodies upstream of the components. A two component final optical element of  $\text{CaF}_2$  is also disclosed.

Fig. 6



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## Description

### Field

[0001] The present invention relates to a lithographic apparatus and a method for manufacturing a device.

### Background

[0002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction. It is also possible to transfer the pattern from the patterning device to the substrate by imprinting the pattern onto the substrate.

[0003] It has been proposed to immerse the substrate in the lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system and also increasing the depth of focus.) Other immersion liquids have been proposed, including water with solid particles (e.g. quartz) suspended therein.

[0004] However, submersing the substrate or substrate and substrate table in a bath of liquid (see for example US 4,509,852, hereby incorporated in its entirety by reference) means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

[0005] One of the solutions proposed is for a liquid supply system to provide liquid on only a localized area of the substrate and in between the final element of the projection system and the substrate using a liquid con-

finement system (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a -X direction, liquid is supplied at the +X side of the element and taken up at the -X side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element.

[0006] Another solution which has been proposed is to provide the liquid supply system with a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. Such a solution is illustrated in Figure 4. The seal member is substantially stationary relative to the projection system in the XY plane though there may be some relative movement in the Z direction (in the direction of the optical axis). A seal is formed between the seal member and the surface of the substrate. Preferably the seal is a contactless seal such as a gas seal. Such a system with a gas seal is disclosed in European Patent Application No. 03252955.4 hereby incorporated in its entirety by reference.

[0007] In European Patent Application No. 03257072.3 the idea of a twin or dual stage immersion lithography apparatus is disclosed. Such an apparatus is provided with two stages for supporting the substrate. Leveling measurements are carried out with a stage at a first position, without immersion liquid, and exposure is carried out with a stage at a second position, where immersion liquid is present. Alternatively, the apparatus has only one stage.

[0008] The use of immersion liquid in the space between the final element of the projection system and the substrate means that the final element of the projection system (e.g. an 'abschlussplatte' which seals the projection system, or the final optical element of the projection system) and substrate table are in contact with the immersion liquid. This can lead to problems with reaction or dissolution in the immersion liquid of the components of the projection system or substrate table.

## SUMMARY

[0009] It is desirable to provide a lithographic projection apparatus in which degradation of components, because of contact with immersion liquid, is reduced.

[0010] According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said final element has, on a surface in contact with said immersion liquid, a protective coating which is substantially insoluble in said immersion liquid.

[0011] In this way the final element of the projection system may be made of a material which is selected due to superior optical properties and considerations regarding the activity between the material of the element and the immersion liquid do not be taken into count. If the thickness of the protective coating is kept low, the effect of the protective coating on the projection beam is minimized.

[0012] Preferably said protective coating is a metal, a metal oxide or nitride e.g. TiN, diamond, DLC or SiO<sub>2</sub>. These materials have been found to be both transparent to projection beam radiation used in immersion lithography as well as insoluble or inert in the immersion liquid, which is preferably comprised substantially of water.

[0013] According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said liquid supply system comprises means for providing a first immersion liquid in said space in contact with said final element and a second immersion liquid in said space in contact with said substrate.

[0014] This arrangement allows the first immersion liquid to be chosen such that the material of the final element of the projection system is insoluble (and/or inert) in that liquid. On the other hand, the second immersion liquid, different from the first, can be selected such that it has the correct optical properties or otherwise as required. Preferably the first and second liquids are kept apart so that it can be ensured that only the first liquid is in contact with the element.

[0015] Preferably the liquid supply system has a membrane for separating the first and second immersion liquids. This is one of many ways in which the two immersion liquids can be arranged to be correctly constrained relative to the final element and the substrate: Material of which the membrane could be made is quartz, preferably between 0.1 and 5mm thick. In this way the final element of the projection system can be protected from the second immersion liquid with only a

small adverse effect to the quality of the projection beam. Other solutions are available.

[0016] According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said final element is comprised of first and second components of CaF<sub>2</sub> or SiO<sub>2</sub> or a combination of both materials, said components being arranged such that said projection beam passes through said first component before passing through said second component.

[0017] In this arrangement it is the last optical element with optical power and/or the abschlussplatte which is referred to. In this way the good optical properties of CaF<sub>2</sub> may be harnessed because the first and second components of CaF<sub>2</sub> can be used to cancel out the effect of the intrinsic birefringence of the other component. One way of doing this is to provide the first and second components with crystal axes aligned such that the intrinsic birefringence of said first component is compensated for by the intrinsic birefringence of said second component.

[0018] Preferably the first and second components are concentric. This is a compact geometry in which the optical paths through the first component are substantially of equal length to those through the second component. In this arrangement the second component may be positioned substantially within a recess in the first component such that if the final lens element is substantially of hemispherical shape the second lens component is substantially hemispherical in shape and the first component is also substantially of hemispherical shape though with a (substantially hemispherical) recess in the non spherical surface.

[0019] It is preferable that only the final element of the projection system is made of CaF<sub>2</sub> and that other elements of the projection system can be made of materials other than CaF<sub>2</sub>.

[0020] According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said liquid supply system comprises at least one sacrificial body in said immersion liquid upstream of said space, for dissolving in said immersion liquid thereby to reduce the rate of dissolution of at least one component of said projection system and/or said substrate table and/or liquid supply system.

[0021] This aspect of invention works by the sacrificial body dissolving in the immersion liquid thereby to reduce the activity of the immersion liquid on components downstream of the sacrificial bodies. For example, if the

sacrificial body is made of the same material as the component it is to protect, the immersion liquid becomes substantially saturated in the material of the sacrificial body such that no more such material can be dissolved by the immersion liquid and the component made of that material is thereby protected. One example of such material is quartz.

[0022] If the sacrificial bodies are of a shape with a high surface area to volume ratio (e.g. rods, tubing, fibers), they will dissolve particularly quickly in the immersion liquid which is advantageous.

[0023] According to an aspect of the invention, there is provided a device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through an immersion liquid provided in a space between a final element of a projection system and said substrate, wherein a protective coating which is substantially insoluble in said immersion liquid is provided on said final element on a surface thereof in contact with said immersion liquid.

[0024] According to an aspect of the invention, there is provided a device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through a first immersion liquid and a second immersion liquid provided in a space between a final element of a projection system and said substrate, wherein said first immersion liquid is in contact with said final element and said second immersion liquid is in contact with said substrate.

[0025] According to an aspect of the invention, there is provided a device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through a first immersion liquid and a second immersion liquid provided in a space between a final element of a projection system and said substrate, wherein at least one sacrificial body is provided in said immersion liquid upstream of said space, for dissolving in said immersion liquid thereby to reduce the rate of dissolution of at least one component of said projection system and/or said substrate table and/or liquid supply system.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

- Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;
- Figures 2 and 3 depict a liquid supply system used in a prior art lithographic projection apparatus;
- Figure 4 depicts a liquid supply system according to another prior art lithographic projection apparatus;
- Figure 5 depicts another liquid containment system according to an embodiment of the invention;

Figure 6 depicts a final element of the projection system with a protective coating;

Figure 7 depicts a final element of the projection system and a liquid supply system for providing a first immersion liquid and a second immersion liquid;

Figure 8 depicts a liquid supply system according to an embodiment of the present invention;

Figure 9 depicts a protective plate applied to the final element of a projection system according to the invention

Figure 10 depicts a protective plate and liquid layer applied to the final element of a projection system according to the invention; and

Figure 11 depicts a two layer protective coating applied to the final element of a projection system according to the invention.

#### DETAILED DESCRIPTION

[0027] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises:

- an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or DUV radiation).
- a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;
- a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and
- a projection system (e.g. a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0028] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0029] The support structure supports, i.e. bears the weight of, the patterning device. It holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may be a frame or a table, for example, which may be fixed

or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms "reticle" or "mask" herein may be considered synonymous with the more general term "patterning device."

**[0030]** The term "patterning device" used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

**[0031]** The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

**[0032]** The term "projection system" used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term "projection lens" herein may be considered as synonymous with the more general term "projection system".

**[0033]** As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

**[0034]** The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such "multiple stage" machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

**[0035]** Referring to Figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form

part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

**[0036]** The illuminator IL may comprise an adjuster AD for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

**[0037]** The radiation beam B is incident on the patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the mask MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

**[0038]** The depicted apparatus could be used in at least one of the following modes:

1. In step mode, the mask table MT and the sub-

strate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

2. In scan mode, the mask table MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the mask table MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0039] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0040] Figure 5 shows a liquid reservoir 10 between the projection system PL and a substrate W which is positioned on the substrate stage WT. The liquid reservoir 10 is filled with a liquid 11 having a relatively high refractive index, e.g. water, provided via inlet/outlet ducts 13. The liquid has the effect that the radiation of the projection beam is a shorter wavelength in the liquid than in air or in a vacuum, allowing smaller features to be resolved. It is well known that the resolution limit of a projection system is determined, inter alia, by the wavelength of the projection beam and the numerical aperture of the system. The presence of the liquid may also be regarded as increasing the effective numerical aperture. Furthermore, at fixed numerical aperture, the liquid is effective to increase the depth of field.

[0041] The reservoir 10 forms a preferably contactless seal to the substrate W around the image field of

the projection lens PL so that the liquid is confined to fill the space between the substrate's primary surface, which faces the projection system PL, and the final element (e.g. an 'abschlussplatte' which seals the projection system, or the final optical element of the projection system) of the projection system PL. The reservoir is formed by a seal member 12 positioned below and surrounding the final element of the projection lens PL. Thus, the liquid containment system LCS provides liquid on only a localized area of the substrate. The seal member 12 forms part of the liquid containment system LCS for filling the space between the final element of the projection system and the sensor 10 (or substrate W) with a liquid. This liquid is brought into the space below the projection lens and within the seal member 12. The seal member 12 extends a little above the bottom element of the projection lens and the liquid rises above the final element so that a buffer of liquid is provided. The seal member 12 has an inner periphery that at the upper end closely conforms to the shape of the projection system or the final element thereof and may, e.g. be round. At the bottom the inner periphery forms an aperture which closely conforms to the shape of the image field, e.g. rectangular, though this is not necessarily so. The projection beam passes through this aperture.

[0042] The liquid 11 is confined in the reservoir 10 by a seal device 16. As illustrated in Figure 5, the seal device is a contactless seal, i.e. a gas seal. The gas seal is formed by gas, e.g. air or synthetic air, provided under pressure via inlet 15 to the gap between seal member 12 and substrate W and extracted by first outlet 14. The over pressure on the gas inlet 15, vacuum level on the first outlet 14 and the geometry of the gap are arranged so that there is a high-velocity air flow inwards towards the optical axis of the apparatus that confines the liquid 11. As with any seal, some liquid is likely to escape, for example up the first outlet 14.

[0043] Figures 2 and 3 also depict a liquid reservoir defined by inlet(s) IN, outlet(s) OUT, the substrate W and the final element of projection lens PL. Like the liquid containment system of Figure 5 the liquid containment system illustrated in Figures 2 and 3, comprising inlet(s) IN and outlet(s) OUT, supplies liquid to a space between the final element of the projection system and a localized area of the primary surface of the substrate.

[0044] Both of the liquid containment systems LCS of Figures 2 & 3 and Figure 4 as well as other solutions, such as a bath in which the substrate W or whole substrate table WT is immersed, can be used with the present invention described below.

[0045] Figure 6 illustrates in detail the final element 20 of the projection system PL. In the embodiment illustrated in Figure 6 the final element is a final optical element 20 which comprises a first component 25 and a second component 27. The final element 20 of the projection system PL is comprised of first and second components 25, 27 so that the element may be made of a material which exhibits birefringence. A preferred mate-

rial for irradiation at 157 nm is CaF<sub>2</sub> which is transmissive but exhibits birefringence properties at this wavelength. Quartz is barely transmissive at 157nm. CaF<sub>2</sub> is also preferred for 193nm although quartz can also be used at this wavelength. However, quartz lenses suffer from compaction at these wavelengths which can cause radiation to be focused on to small bits of the lens which discolor (go dark) and absorb more heat and so a channel can get cut.

[0046] By providing the final element 20 as first and second components or parts, the birefringence exhibited by CaF<sub>2</sub> at 157 nm can be compensated for by ensuring that the crystal orientations of the first and second components are aligned such that the intrinsic birefringence exhibited by the first component 25 is cancelled by the intrinsic birefringence exhibited by the second component 27. In this way, the projection PB which passes first through the first component 25 and then through the second component 27 exits the second component 27 substantially free of birefringence phenomena.

[0047] The remaining optical elements of the projection system PL may be comprised of materials other than CaF<sub>2</sub>. The intensity of the projection beam is highest at the last element which is also the smallest so that it is this element which is most likely to suffer from compaction if made of quartz.

[0048] As illustrated in Figure 6, the final element 20 of the projection system PL is substantially hemispherical in shape. Thus, the second component 27 is in the shape of a hemisphere and is positioned in a recess of the first component 25 which has an outer surface of the shape of a hemisphere with a recess in its non-curved surface.

[0049] It has been found that CaF<sub>2</sub> may dissolve or react with immersion liquid 11 used in an immersion liquid lithographic projection apparatus. Presently the immersion liquid is envisaged as comprising substantially water for 248 and 193nm. For 157nm, perfluoro-hydrocarbons are envisaged.

[0050] One way of protecting the final element 20 of the projection system from attack by the immersion liquid 11 is to provide a protective coating 40 on a surface of the final element 20 which is in contact with the immersion liquid. The material of the protective coating 40 is preferably inert in the immersion liquid 11 and does not dissolve. As is illustrated in Figure 6, the protective coating 40 is attached to the bottom (as illustrated) surface of the second component 27 of the projection system PL.

[0051] It is preferable to make the protective layer as thin as possible while still providing protection to the final optical element 20 of the projection system PL. The protective coating is preferably between 5 and 500 nm thick, more preferably between 10 and 200 nm thick. Preferably material of the protective coating 40 is a metal, a metal oxide or nitride or SiO<sub>2</sub> with a low contact angle with the immersion fluid to limit bubble inclusion.

The layer may be deposited on the element 20 by e.g. evaporation, sputtering etc.

[0052] The use of a protective coating 40 is not limited to the case where the final element 20 of the projection system PL is comprised of CaF<sub>2</sub>. For example, if the final element is comprised of quartz (as typically in the case of an abschlussplatte being the final element), there may also be problems due to the dissolution or reaction of quartz with the immersion liquid 11. In this case a protective layer 40 may also be required.

[0053] The protective coating 40 should be as thin as possible to minimize transmission losses. The refractive index of the protective coating 40 can be partially varied by the deposition process and the deposition parameters. Experience gained in the deposition of EUV coatings might be usefully harnessed to optimize this process.

[0054] Figure 7 illustrates a second embodiment of the present invention which is the same as the first embodiment except as described below.

[0055] In this embodiment the liquid supply system comprises means for providing a first immersion liquid 70 which is in contact with the final element 20 of the projection system. A second immersion liquid 75 is also provided which is in contact with the substrate W.

[0056] The first immersion liquid 70 can be chosen such that it only reacts with or dissolves very slowly the material of the final element 20 or does not react at all. The second immersion liquid 75 can then be chosen because of its good optical properties without any activity limitations being placed on it because of its contact with the final element 20.

[0057] There are several ways that the two immersion liquids 70, 75 may be provided to the correct areas of the space and kept substantially apart. For example, it may be possible to provide two sets of inlets and outlets to give two flows of liquid, especially if the first and second immersion liquids are immiscible or not easily mixed.

[0058] In the embodiment illustrated in Figure 7, a membrane 50 is provided for separating the first and second 70, 75 immersion liquids. The immersion liquids 70, 75 may then be provided separately on either side of the membrane.

[0059] Preferably the membrane is between 0.1 and 5mm thick to give the required stiffness without seriously deleteriously affecting the quality of the projection beam PB. As suitable material for making the membrane 50 is SiO<sub>2</sub>. The membrane 50 may be replaceable.

[0060] Figure 8 illustrates a liquid supply system which may be used with either of the above two embodiments. The liquid supply system 100 provides liquid from an inlet 102 to a liquid containment system LCS which may be any type of liquid containment system, especially of the types illustrated in Figures 2 to 5. In the Figure 8 embodiment, the immersion liquid is provided between the abschlussplatte 90 and the substrate W. Immersion liquid exits then via a drain 104.

[0061] Components of the liquid containment system, the projection system PL and the substrate table WT all come in contact with the immersion liquid. If any of those components are made of a material which can dissolve in untreated immersion liquid, and are not protected, this can deleteriously effect the lifetime of the apparatus.

[0062] In order to address this problem a sacrificial unit 80 is provided upstream of the liquid containment system LCS in the liquid supply system 100. In the sacrificial unit 80 at least one sacrificial body 85 is positioned. The sacrificial body 85 is intended to dissolve in the immersion liquid thereby to reduce the activity of the immersion liquid with materials of the components to be protected in the projection system and/or of the substrate table and/or of the liquid containment system downstream.

[0063] For example, if the final element of the projection system PL e.g. an abschlussplatte 90 (last lens element) is comprised of quartz and is in contact with the immersion liquid, if at least one of the sacrificial bodies is comprised of quartz, the immersion liquid (which may be water) can be saturated with quartz as it passes through the sacrificial unit 80 such that the immersion liquid activity with quartz once it reaches the liquid containment system LCS and abschlussplatte 90 is reduced.

[0064] The sacrificial unit 80 may contain a plurality of sacrificial bodies which are not necessarily all of the same material. It may also be that the sacrificial bodies may be made of a different material to those materials which they are intended to protect. For example, a sacrificial body may be designed to reduce the pH of the immersion liquid to such a level that materials of components to be protected downstream of the sacrificial unit 80 do not dissolve. Alternatively, a buffer could be added to the liquid.

[0065] It is advantageous that the sacrificial bodies 85 have as large as possible a surface area to volume ratio. Example shapes are rods, tubes, etc.. However, clearly any shape can be used.

[0066] In a further embodiment of the invention, shown in Figure 9, the final element 20 of the projection system is protected by a fused silica plate 45. This plate may have a thickness in the range of from 50µm to 5mm and may be contact bonded or glue bonded to the final element 20. In contact bonding, no glue is used - the bonding surfaces are made smooth and clean enough to directly bond together. After bonding to the final element, the fused silica plate may be ground and polished to the desired thickness, avoiding difficulties inherent in handling a very thin plate. A liquid-tight seal 46 may be provided around the perimeter of the join.

[0067] A seal 46 around the join of the final element and the fused silica protective plate is especially desirable where the final element and fused silica plate are contact bonded together. Although this form of bonding can provide an exceptionally strong bond, where dissimilar materials, such as CaF and fused silica, are bonded

temperature changes and thermal gradients can cause the bond to "breathe" - differential thermal expansion or contraction of the two materials causes them to separate until the stress is relieved. Although the bond usually reforms very quickly in the case of thermal separation, if this occurs when the final element is in contact with a liquid, e.g. during polishing or grinding of the protective layer or use of the apparatus, liquid can be drawn into the gap.

[0068] One form of seal that may be used is a layer of SiO formed by applying a suitable precursor (such as silicone fluids (i.e. comprising Si-O chains of various lengths with various hydrocarbon side-chains), tetraethyl orthosilicate, decamethyl tetrasiloxane and tetrabutyl orthosilicate) and irradiating it with DUV light to photo-convert the precursor to SiO. This form of seal has the advantage that it has a similar hardness to the fused silica plate and so polishes at a similar rate.

[0069] Another form of seal that is useful is a silicon caulk provided over a layer of titanium oxide. The titanium oxide is applied by painting a precursor onto the seal and photo-converting it to titanium oxide and acts to protect the silicone caulk from UV light during operation of the apparatus.

[0070] A further form of seal is formed by painting tetraethyl orthosilicate around the join, which then decomposes at room temperature to form a thin layer of fused silica which forms a seal. This seal is however rather brittle so that careful handling is required.

[0071] In a variant of the Figure 9 arrangement shown in Figure 10, a liquid 47, such as oil, is provided between the last lens element 20 and the protective plate 45. The liquid 47 preferably has a refractive index as close as possible to that of the immersion fluid 11, which may be water, but is not damaging to the material of the final lens element 20, which may be CaF<sub>2</sub>. This enables the protective plate to be interchangeable by substantially reducing the requirements on the accuracy with which the protective plate 45 must be positioned as the fluids above and below it have similar refractive indexes.

[0072] A further variant of the present invention, shown in Figure 11 uses a two layer protective coating, made up of inner layer 48 and outer layer 49. It can be very difficult to form a layer of protective coating, without pinholes. Even the smallest pinhole in a protective coating applied to a CaF body allows dissolution of the CaF body when immersed in water, causing cavitation which is extremely deleterious to the optical properties of the element. By the use of a two layer protective coating, it can be arranged that the pinholes in one layer do not match up with the pinholes in the other layer so that there is no through path in the protective layer. It can best be ensured that the pinholes of the two layers do not match up by applying the two protective layers by different methods.

[0073] A preferred embodiment of the invention has a first layer 48 of SiO applied by sputtering and a second layer 49 applied by spin coating a precursor and photo-



converting the precursor to SiO. This method has been found to be more effective than sputtering two layers of SiO since the pinholes in the second sputtered layer have a tendency to line up with those in the first layer. Surprisingly, it has been found that the spin coating and photo-conversion method provides a layer of bulk SiO rather than porous SiO. A layer formed by spin-coating a precursor and then photo-converting it to SiO may also be used on its own as a seal layer.

**[0074]** The precursor used to form protective layer 49 may be any suitable fluid of, or containing, organo-silicon compounds. Suitable examples are silicone fluids (i.e. comprising Si-O chains of various lengths with various hydrocarbon side-chains), tetraethyl orthosilicate, decamethyl tetrasiloxane and tetrabutyl orthosilicate. The material may be chosen to have a desired viscosity to enable a suitably even layer to be provided by spin coating. Solvents, preferably volatile organic solvents, may be used to adjust the viscosity if necessary.

**[0075]** Photo-conversion of the precursor to SiO can be achieved with irradiation by DUV light of various wavelengths, e.g. 184nm or 172nm, at a rate determined to avoid any deleterious effects that might be induced by thermal gradients in the element.

**[0076]** Each of the two layers of the protective coating may have a thickness in the range of 50 to 200nm.

**[0077]** Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "wafer" or "die" herein may be considered as synonymous with the more general terms "substrate" or "target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

**[0078]** The terms "radiation" and "beam" used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 248, 193, 157 or 126 nm).

**[0079]** The term "lens", where the context allows, may refer to any one or combination of various types of optical components, including refractive and reflective optical components.

**[0080]** While specific embodiments of the invention

have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, the invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

**[0081]** The present invention can be applied to any immersion lithography apparatus, in particular, but not exclusively, those types mentioned above.

**[0082]** The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

## Claims

1. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said final element has, on a surface in contact with said immersion liquid, a protective coating which is substantially insoluble in said immersion liquid.
2. A lithographic projection apparatus according to claim 1, wherein said protective coating has a thickness equal to or greater than 5 nm.
3. A lithographic projection apparatus according to claim 1 or 2, wherein said protective coating has a thickness less than or equal to 500nm
4. A lithographic projection apparatus according to claim 1, 2 or 3, wherein said protective coating is a metal, a metal oxide or nitride, CaF<sub>2</sub>, SiO, SiO<sub>2</sub> or a combination of these materials.
5. A lithographic projection apparatus according to claim 1 wherein said protective coating is a fused silica plate.
6. A lithographic projection apparatus according to claim 5 wherein said fused silica plate has a thickness in the range of from 50µm to 5mm.
7. A lithographic projection apparatus according to claim 5 or 6 wherein said fused silica plate is attached to said final element by contact bonding without glue.
8. A lithographic projection apparatus according to

- claim 1 wherein said protective coating has two distinct layers.
9. A lithographic projection apparatus according to claim 8 wherein said two distinct layers are of the same material but have been formed by different methods. 5
  10. A lithographic projection apparatus according to claim 9 wherein one of said two distinct layers is formed by sputtering and the other of said two distinct layers is formed by spin coating a precursor onto said final element and irradiating said precursor with ultraviolet light. 10
  11. A lithographic projection apparatus according to claim 1 wherein said protective coating is formed by spin coating a precursor onto said final element and irradiating said precursor with ultraviolet light. 15
  12. A lithographic projection apparatus according to claim 10 or 11 wherein said precursor comprises an organo-silicon compound. 20
  13. A lithographic projection apparatus according to claim 12 wherein said precursor comprises at least one compound selected from the group comprising silicone fluids, tetraethyl orthosilicate, decamethyl tetrasiloxane and tetrabutyl orthosilicate. 25
  14. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said liquid supply system comprises means for providing a first immersion liquid in said space in contact with said final element and a second immersion liquid in said space in contact with said substrate. 30
  15. A lithographic projection apparatus according to claim 14, wherein said liquid supply system further comprises a membrane for separating said first and second immersion liquids. 35
  16. A lithographic projection apparatus according to claim 15, wherein said membrane is quartz. 40
  17. A lithographic projection apparatus according to claim 15 or 16, wherein said membrane has a thickness in the range of 0.1 to 5mm. 45
  18. A lithographic projection apparatus according to any one of the preceding claims, wherein said final element is comprised of  $\text{CaF}_2$ . 50
  19. A lithographic projection apparatus according to claim 18, wherein said final element is comprised of a first and a second component, both components being of  $\text{CaF}_2$ , wherein said projection beam passes through said first component before passing through said second component. 55
  20. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said final element is comprised of first and second components of  $\text{CaF}_2$  or  $\text{SiO}_2$  or a combination of both materials, said components being arranged such that said projection beam passes through said first component before passing through said second component.
  21. A lithographic projection apparatus according to claim 19 or 20, wherein said first and second components each have crystal axes which are aligned such that intrinsic birefringence of said first component is compensated for by intrinsic birefringence of said second component.
  22. A lithographic projection apparatus according to claim 19, 20 or 21, wherein said first and second components are concentric.
  23. A lithographic projection apparatus according to any one of claims 19 to 22, wherein said second component is positioned substantially within a recess in said first component.
  24. A lithographic projection apparatus according to any one of claims 19 to 23, wherein elements of said projection system other than said final element are made of (a) material(s) other than  $\text{CaF}_2$ .
  25. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with an immersion liquid, wherein said liquid supply system comprises at least one sacrificial body in said immersion liquid upstream of said space, for dissolving in said immersion liquid thereby to reduce the rate of dissolution of at least one component of said projection system and/or said substrate table and/or liquid supply system.
  26. A lithographic projection apparatus according to claim 25, wherein said at least one sacrificial body is made of substantially the same material as said at least one component.

27. A lithographic projection apparatus according to claim 25 or 26, wherein said at least one sacrificial body is made of quartz or CaF<sub>2</sub>.
28. A lithographic projection apparatus according to claim 25, 26 or 27, wherein said at least one sacrificial body is of a shape with a high surface area to volume ratio.
29. A device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through an immersion liquid provided in a space between a final element of a projection system and said substrate, wherein a protective coating which is substantially insoluble in said immersion liquid is provided on said final element on a surface thereof in contact with said immersion liquid.
30. A device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through a first immersion liquid and a second immersion liquid provided in a space between a final element of a projection system and said substrate, wherein said first immersion liquid is in contact with said final element and said second immersion liquid is in contact with said substrate.
31. A device manufacturing method comprising projecting a patterned beam of radiation onto a substrate through a first immersion liquid and a second immersion liquid provided in a space between a final element of a projection system and said substrate, wherein at least one sacrificial body is provided in said immersion liquid upstream of said space, for dissolving in said immersion liquid thereby to reduce the rate of dissolution of at least one component of said projection system and/or said substrate table and/or liquid supply system.

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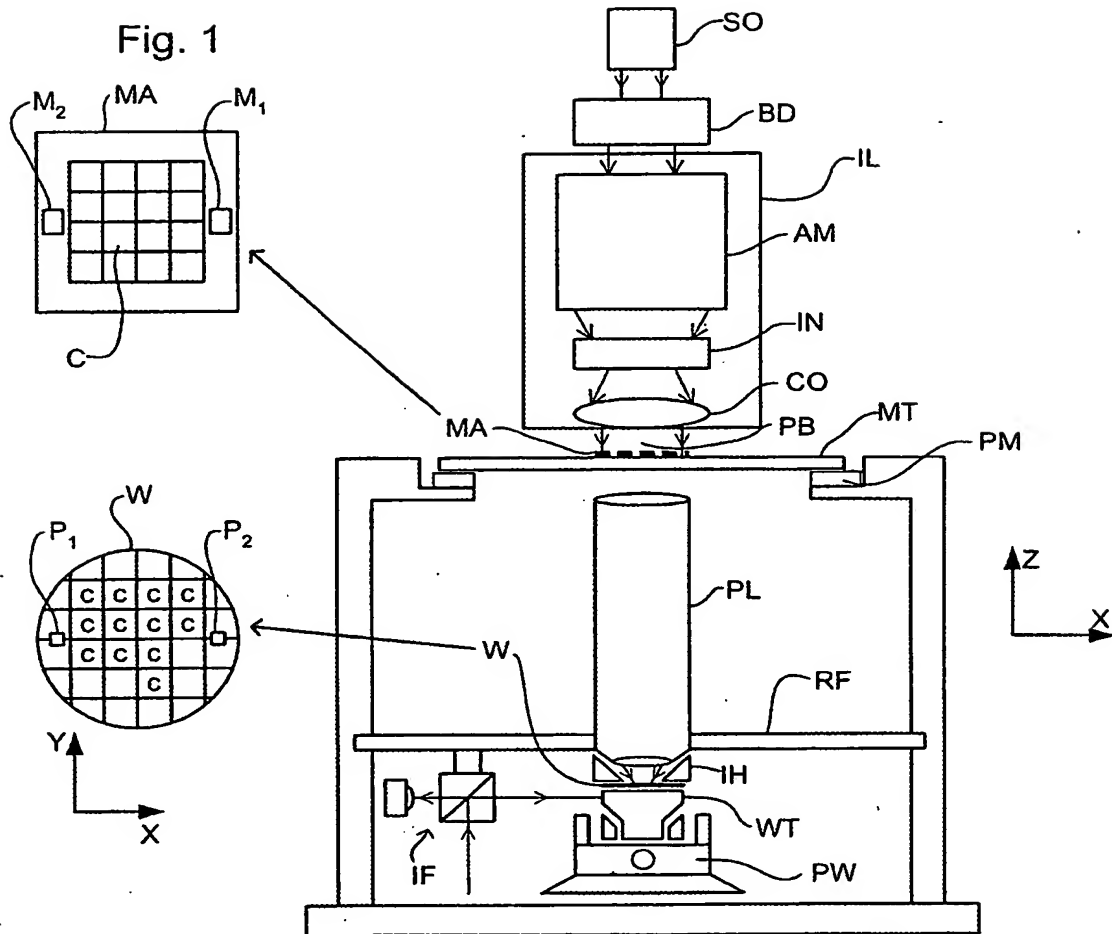


Fig. 2

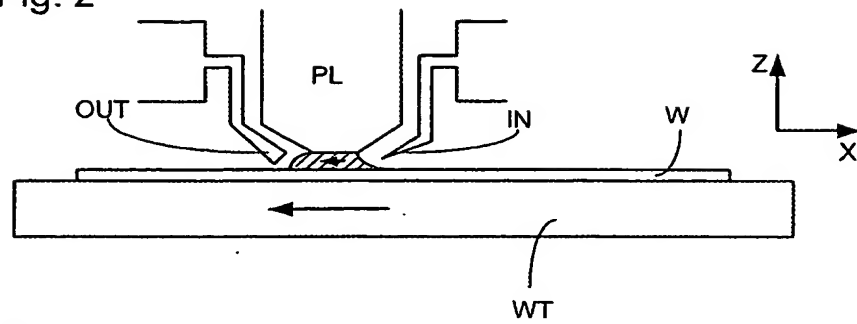


Fig. 3

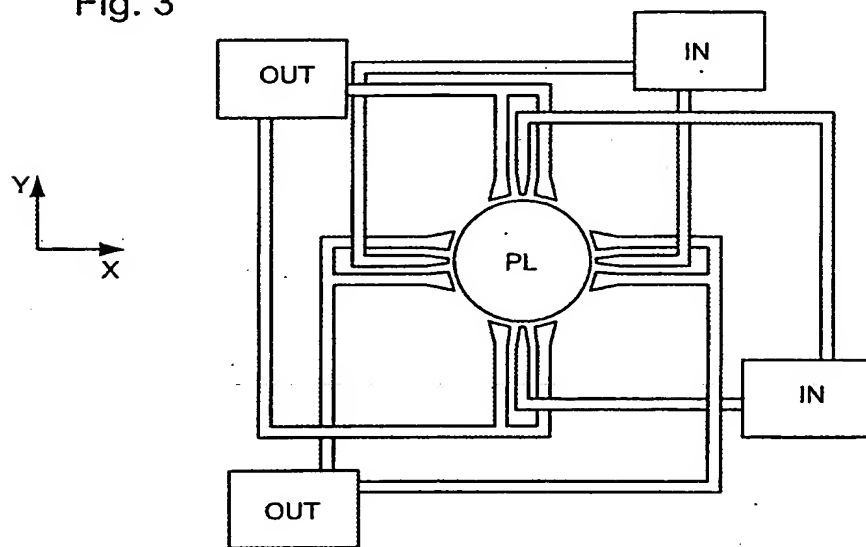


Fig. 4

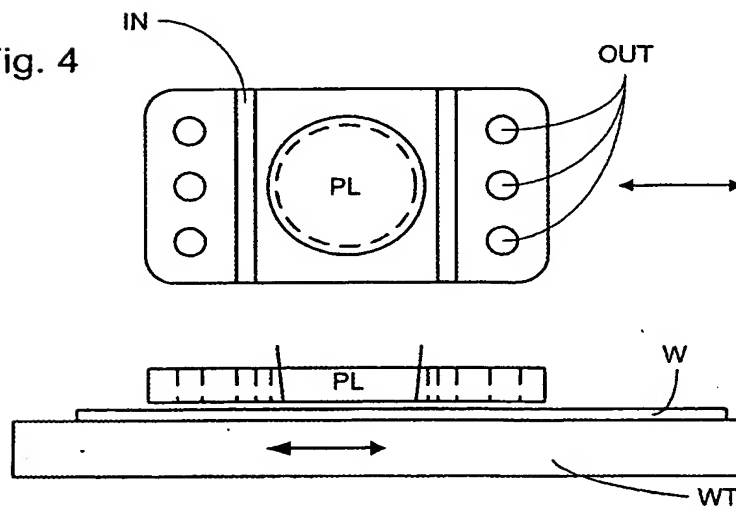


Fig. 5

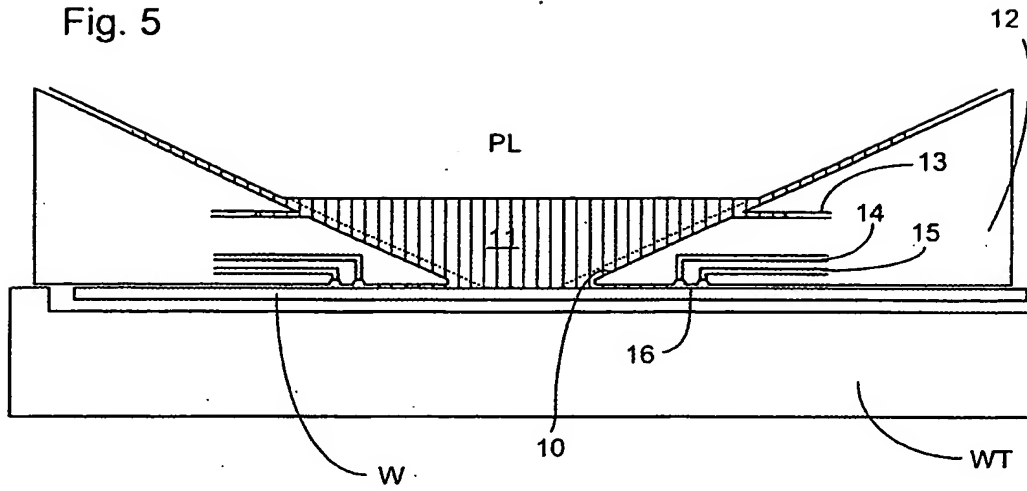


Fig. 6

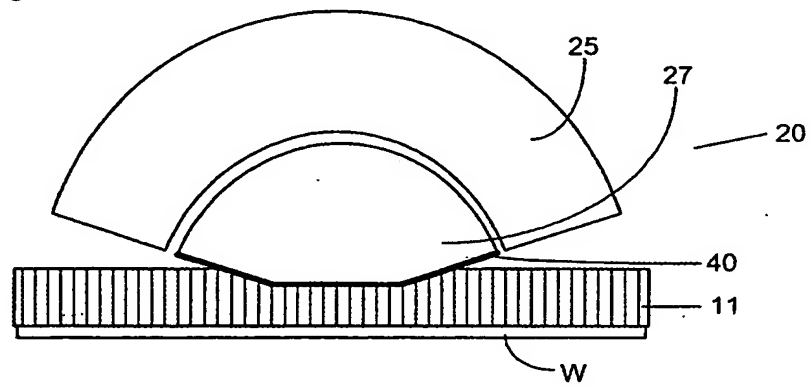


Fig. 7

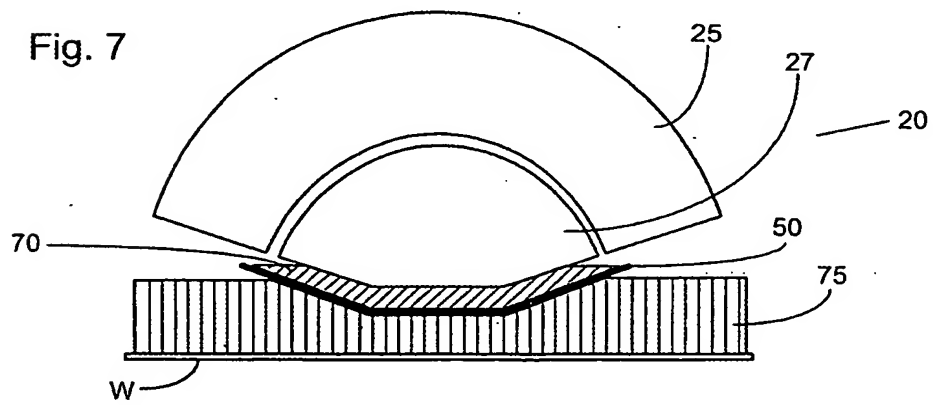


Fig. 8

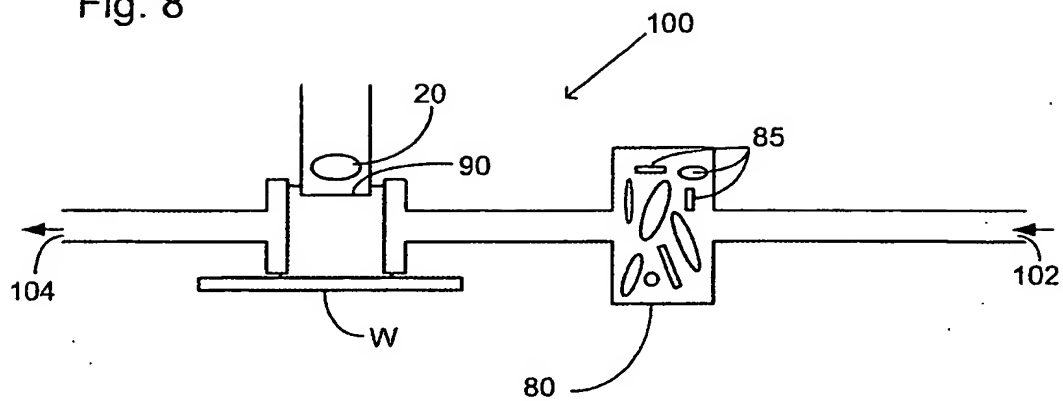


Fig. 9

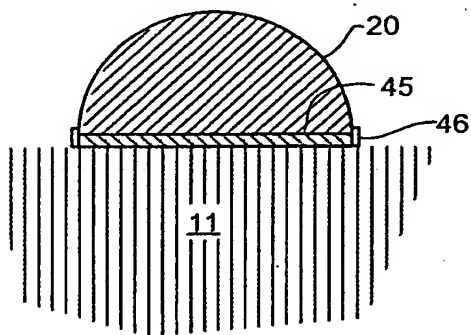


Fig. 10

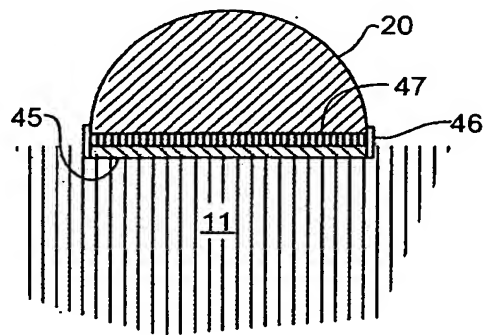
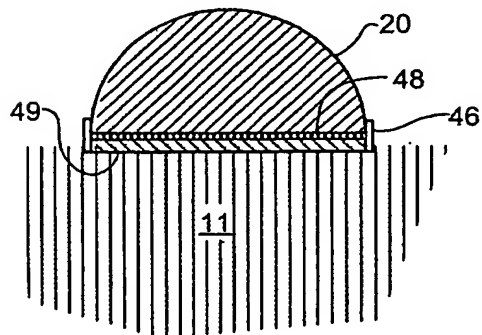


Fig. 11



(19)



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(11)

EP 1 510 871 A3

(12)

## EUROPEAN PATENT APPLICATION

(88) Date of publication A3:  
06.04.2005 Bulletin 2005/14

(51) Int Cl.7: G03F 7/20

(43) Date of publication A2:  
02.03.2005 Bulletin 2005/09

(21) Application number: 04254940.2

(22) Date of filing: 17.08.2004

(84) Designated Contracting States:  
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IT LI LU MC NL PL PT RO SE SI SK TR  
Designated Extension States:  
AL HR LT LV MK

(30) Priority: 29.08.2003 EP 03255377

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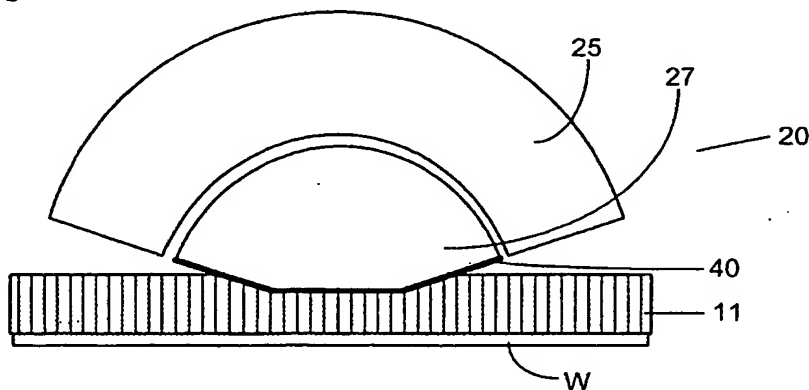
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### (54) Lithographic apparatus and device manufacturing method

(57) A lithographic projection apparatus is disclosed for use with an immersion liquid positioned between the final element of the projection system and the substrate W. Several methods are disclosed for protecting components of the projection system, substrate table and a

liquid confinement system. These include providing a protective coating (40) on the final element (20) of the projection system as well as providing sacrificial bodies upstream of the components. A two component final optical element of  $\text{CaF}_2$  is also disclosed.

Fig. 6



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## EUROPEAN SEARCH REPORT

Application Number

EP 04 25 4940

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Place of search The Hague		Date of completion of the search 4 February 2005	Examiner Aguilar, M.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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## EUROPEAN SEARCH REPORT

Application Number  
EP 04 25 4940

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Place of search The Hague		Date of completion of the search 4 February 2005	Examiner Aguilar, M.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**CLAIMS INCURRING FEES**

The present European patent application comprised at the time of filing more than ten claims.

- ☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

**LACK OF UNITY OF INVENTION**

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:



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LACK OF UNITY OF INVENTION  
SHEET B

Application Number  
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The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-13, 18, 19, 21-24, 29 (insofar as claims 18, 19, 21-24 relate to invention 1)

Prior art features: immersion lithographic projection apparatus with a coating on the final optical element.  
Special technical features (of suitably amended claims): particular type of protective coating.  
Problem solved by these special technical features: protection of the final optical element from the immersion liquid.

2. claims: 14-17, 18, 19, 21-24, 30 (insofar as claims 18, 19, 21-24 relate to invention 2)

Prior art features: immersion lithographic projection apparatus.  
Special technical features: first immersion liquid in contact with final optical element and second immersion liquid in contact with the substrate.  
Problem solved by these special technical features: protection of the final optical element from the immersion liquid.

3. claims: 20-24 (insofar as claims 21-24 relate to invention 3)

Prior art features: immersion lithographic projection apparatus with a coating on the final optical element.  
Special technical features: final optical element comprises two components.  
Problem solved by these special technical features: eliminating birefringence.

4. claims: 25-28, 31

Prior art features: immersion lithographic projection apparatus.  
Special technical features: sacrificial body in immersion liquid  
Problem solved by these special technical features: protection of the final optical element from the immersion liquid.

**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 04 25 4940

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
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